

ϕ -Meson Production at RHIC Energies using the PHENIX Detector

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For the PHENIX collaboration.

7th October, 2008



Outline

1 Motivation

2 The PHENIX detector

3 $\phi \rightarrow K^+K^-$ and $\phi \rightarrow e^+e^-$

- ϕ spectra
- Yield and Temperature

4 Elliptic flow

- v_2 of ϕ

5 Nuclear Modification Factor

- R_{dA} and R_{AA}

6 Summary

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Motivation

ϕ -meson, a unique probe

ϕ is a vector meson with hidden strangeness($s\bar{s}$). It is a good probe as:

- Its production is OZI suppressed in p+p collisions.
- Small cross-section with non-strange hadrons, lifetime $\tau \sim 46\text{fm}/c$.
 - carries information from the early partonic stages of the system evolution.
- It is comparable in mass to Λ, p baryons, so its v_2 and R_{AA} provide a critical test for mass or meson/baryon or quark content dependencies and an insight into properties of the medium formed.
- A diagnostic probe to Chiral Symmetry Restoration that can manifest itself in:
 - *line shape (peak position and/or width) modifications.* $\tau_\phi = 46\text{fm}/c, \tau_{QGP} = 10\text{fm}/c \Rightarrow$ only a small fraction of ϕ decays inside the fireball producing a very small modification in the line shape.
 - *change in the BR of the ϕ decay through e^+e^- compared to the K^+K^- decay channel.* ($m\phi \sim 2M_K \Rightarrow$ small changes in ϕ or K can induce significant change in BR)

PHENIX measures ϕ through both e^+e^- and K^+K^- decay channels. However present quality of data does not allow to address this issue of chiral symmetry restoration.

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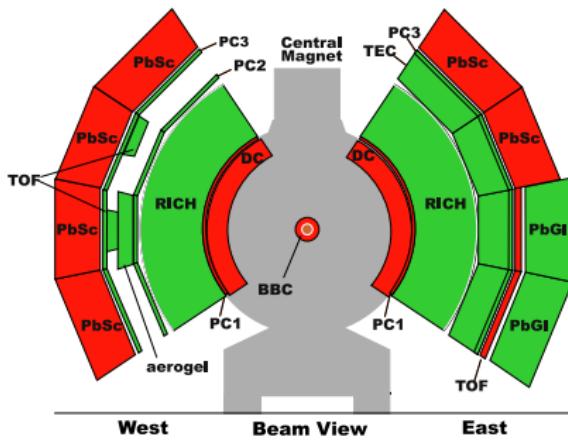
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The PHENIX detector

PHENIX Central arms Acceptance:

$$-0.35 < \eta < 0.35,$$

$2 \times 90^\circ$ for two arms



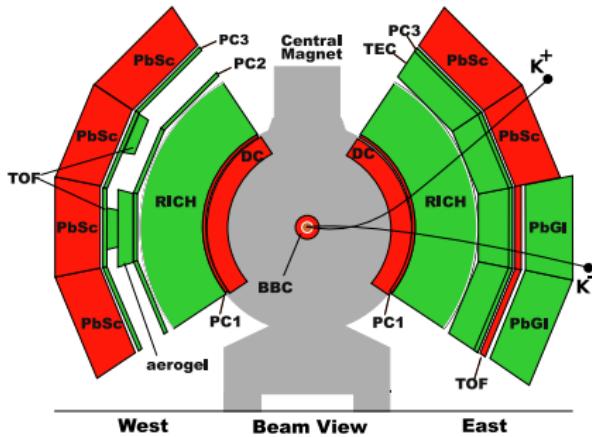
- Vertex: **BBC**
- Tracking: **DC/PC1**
- Matching: **PC3**
- Trigger:
 - Min. bias: **BBC**
 - e: **RICH, EmCal**
- h ID: Time-of-flight
 - **TOF** $d\tau \sim 100$ ns
 - **EmCal** $d\tau \sim 500$ ns
 - **Aerogel** $d\tau \sim 500$ ns
- e ID:
 - Čerenkov light **RICH** (e/π rejection >1000)
 - E-p matching **EmCal** ~ 10

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Measured decays of ϕ

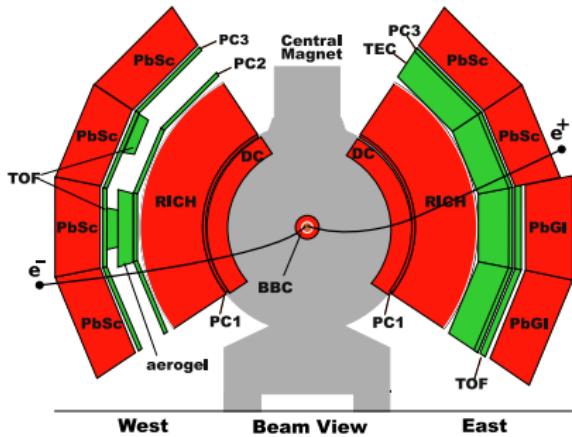
- $\phi \rightarrow K^+ K^-$: BR = $49.2 \pm 0.7\%$

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Measured decays of ϕ

- $\phi \rightarrow K^+ K^-$: **BR** = $49.2 \pm 0.7\%$
- $\phi \rightarrow e^+ e^-$: **BR** = $(2.97 \pm 0.04) \times 10^{-4}$

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$$\phi \rightarrow K^+K^- \text{ and } \phi \rightarrow e^+e^-$$

Analysis details -I

$\phi \rightarrow K^+K^-$ measured using three techniques

No Kaon identification

All hadron tracks are selected to form pairs without any identification

Advantages:

- allows to go to high p_T .

Disadvantages:

- large background.

One Kaon identified

One out of the two candidates in the pair, is required to be identified as a Kaon

- less background as compared to no ID and as a consistency check.

Both Kaons identified

Both tracks should be identified as Kaons

- allows to go lower in p_T as compared to the other two.
- less background.
- limited p_T coverage.

- Together, the 3 analyses provide a consistency check and systematics.
- With no PID method, the measurements in p+p and Au+Au have been extended upto a p_T of 7 GeV/c and to 5.5GeV/c in d+Au.

$$\phi \rightarrow e^+e^-$$

Electron tracks are identified by EMCal and RICH detector.

Signal Extraction

In $d + Au$ and $Au + Au$

- e^+/e^- or K^+/K^- are combined to form foreground (FG) of “+−”, “++”, “−−” pairs.
- Event mixing technique is used to estimate combinatorial background (BG). The events mixed are required to have same event topology (centrality, vertex, reaction plane)
- The BG is normalized by

$$\langle N_{\pm} \rangle = 2\sqrt{\langle N_{++} \rangle \cdot \langle N_{++} \rangle}$$

- Like sign spectra is used as a cross-check for the shape.
- The final subtracted m_{inv} distribution is then fitted with a relativistic Breit-Wigner function convoluted with a Gaussian to take account of the detector resolution.

In $p + p$

- For K^+K^- , the signal is calculated by a RBW function convoluted with Guassian and a polynomial for the BG. The parameters of the function are optimized based on realistic simulations.
- For e^+e^- , event mixing and also a similar technique as that done for K^+K^- , are used. Both methods give same results.

$\phi \rightarrow K^+K^-$ and $\phi \rightarrow e^+e^-$

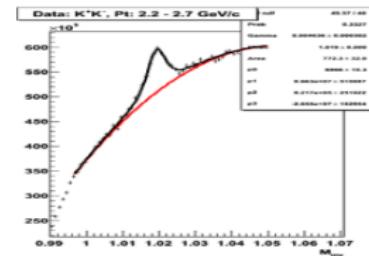
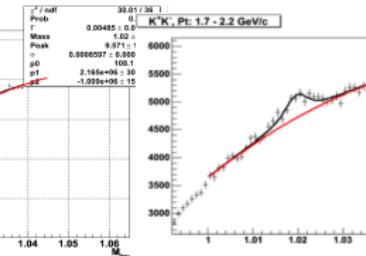
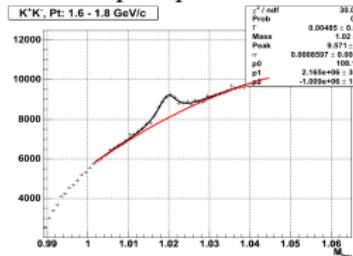
Invariant spectra

$\phi \rightarrow K^+K^-$, $\sqrt{s_{NN}} = 200$ GeV

$p + p$

$d + Au$

$Au + Au$



No Kaon
ID

$\phi \rightarrow K^+K^-$ and $\phi \rightarrow e^+e^-$

Invariant spectra

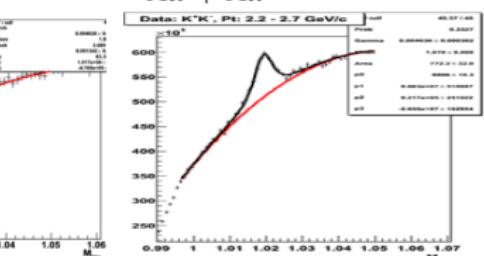
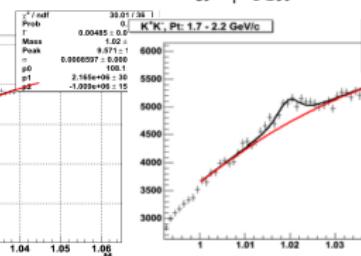
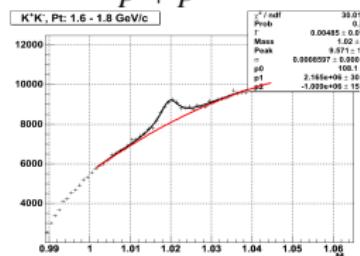
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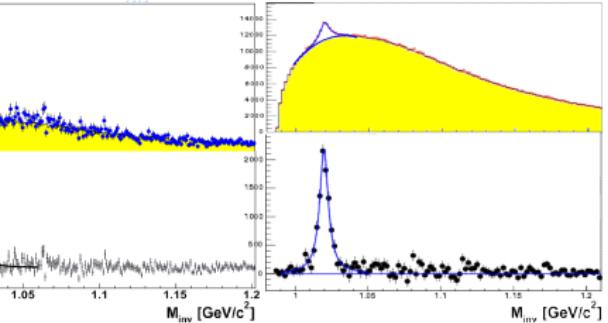
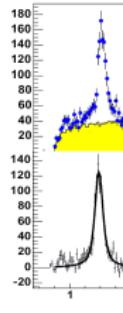
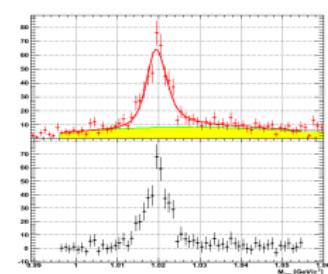
$d + Au$

$Au + Au$

No Kaon ID

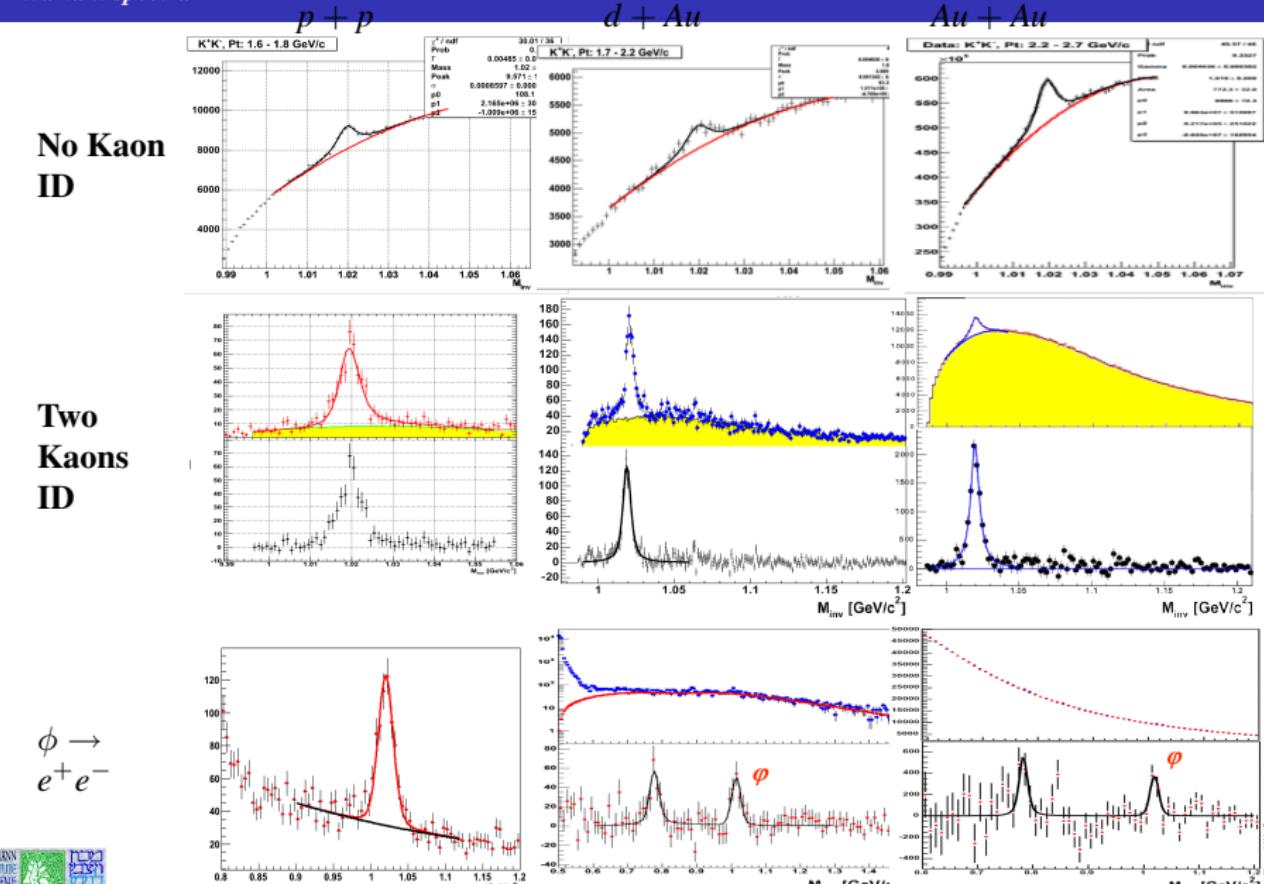


Two Kaons ID



$\phi \rightarrow K^+K^-$ and $\phi \rightarrow e^+e^-$

Invariant spectra



Analysis details-III

Invariant yield

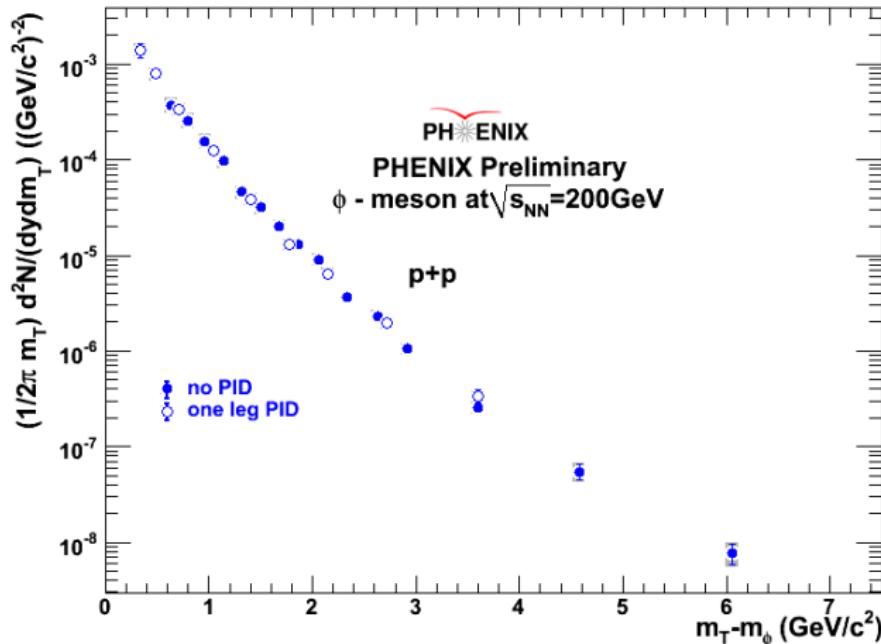
The Invariant yield is calculated as per the following equation:

$$\frac{1}{2\pi m_T} \cdot \frac{d^2N}{dm_T dy} = \frac{1}{2\pi m_T \cdot N_{events} \cdot BR \cdot \Delta m_T} \cdot \frac{N_{raw}^{\phi,\omega}(m_T) \cdot CF(m_T)}{\epsilon_{pair-embedding} \cdot \epsilon_{run-by-run}}$$

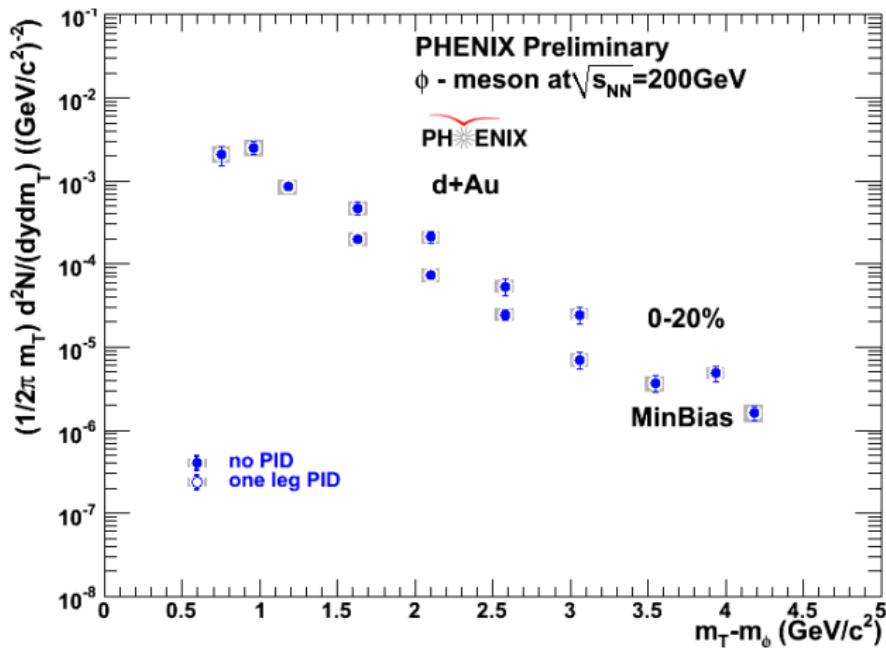
where

- N_{events} correspond to total events analyzed.
- Δm_T is the m_T bin width.
- BR is the branching ratio (PDG) for the decay under study.
- CF is the correction factor from the simulations that takes into account the detector acceptance and reconstruction efficiency.
- $\epsilon_{pair-embedding}$ is pair embedding efficiency to account for losses due to detector occupancy.
- $\epsilon_{run-by-run}$ run by run variations of the detector performance

Data Set

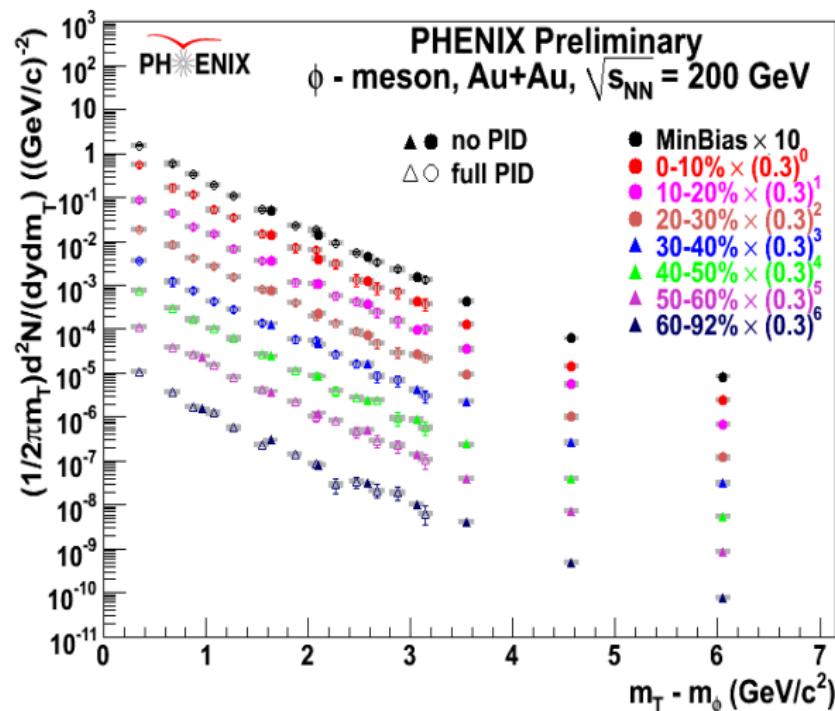


- p+p 200 GeV:
new Run5 measurements
- d+Au 200 GeV:
Run3.
- Au+Au 200 GeV:
Run4
- The different analysis techniques yield same results in $p + p$, $d + Au$ and $Au + Au$
- In $p + p$ and $Au + Au$, the measurements cover p_T range from 0-7 GeV/c
- Au+Au 62.4 GeV:
Run4



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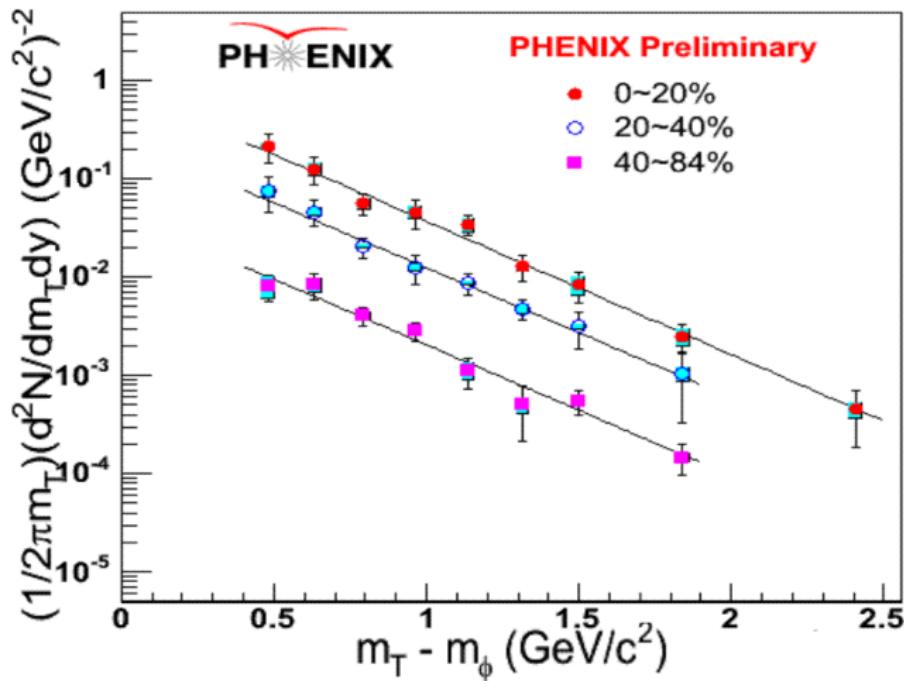
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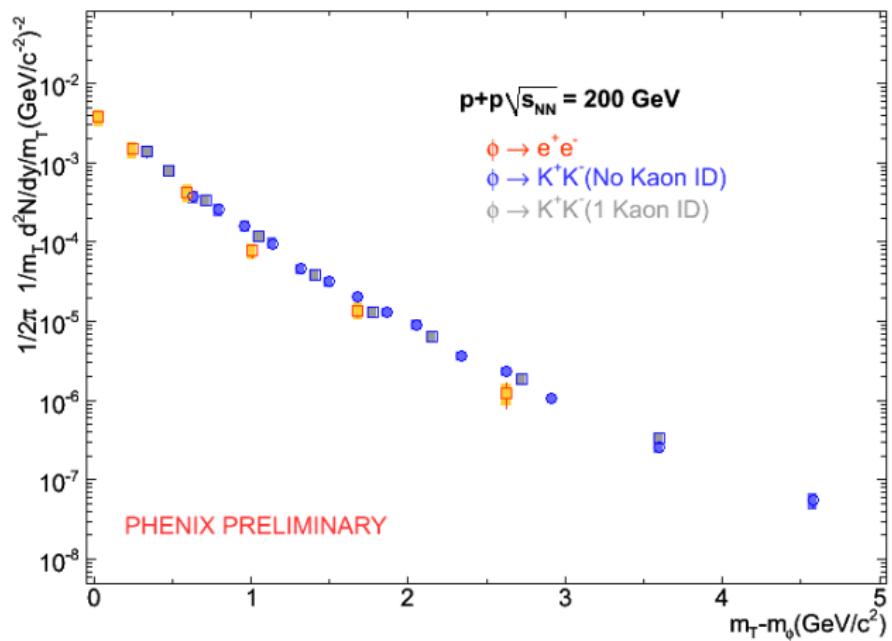
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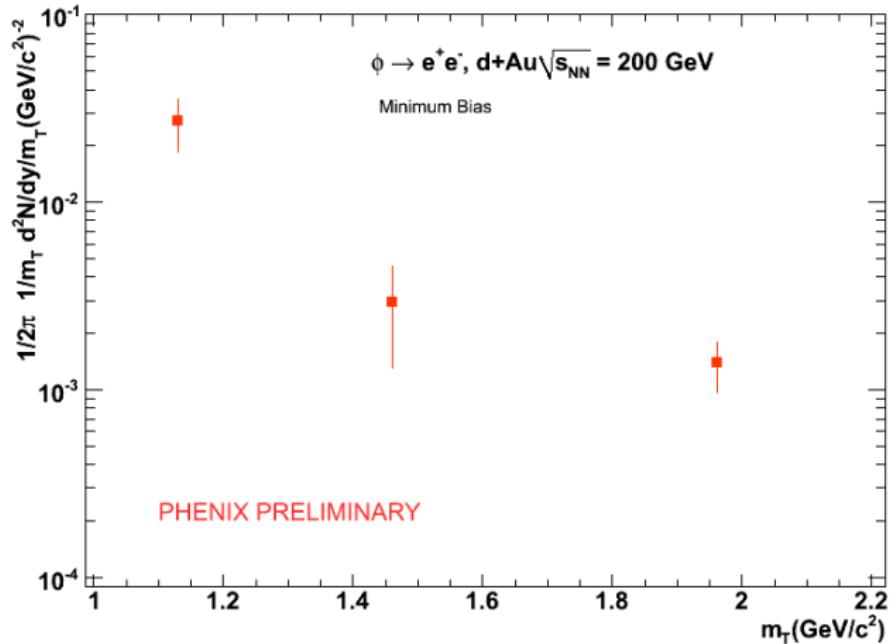


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• Au+Au 200
GeV: Run4

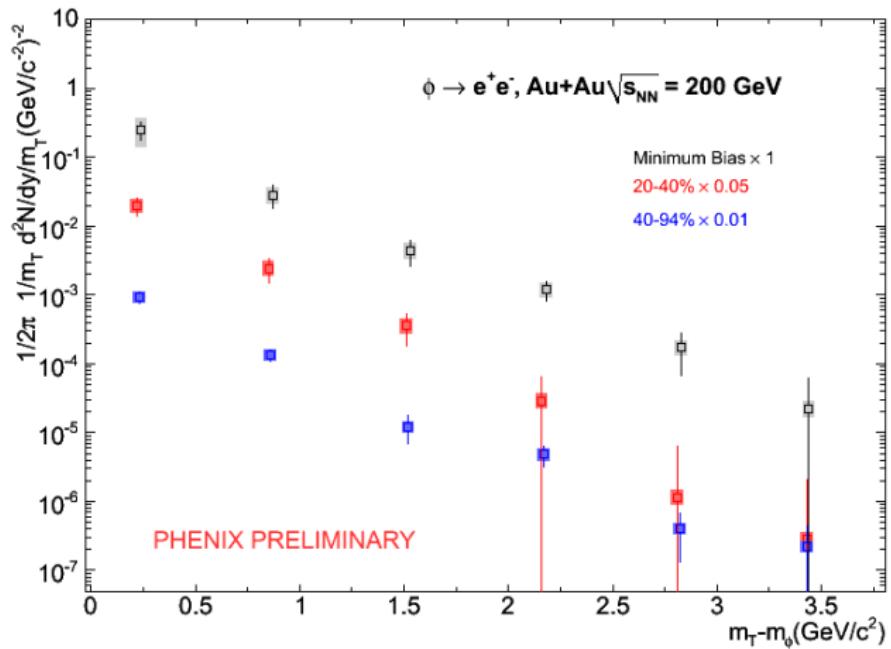
$\phi \rightarrow e^+e^-$ spectra



Data Set

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Run5
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Run3
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$\phi \rightarrow e^+e^-$ spectra



Data Set

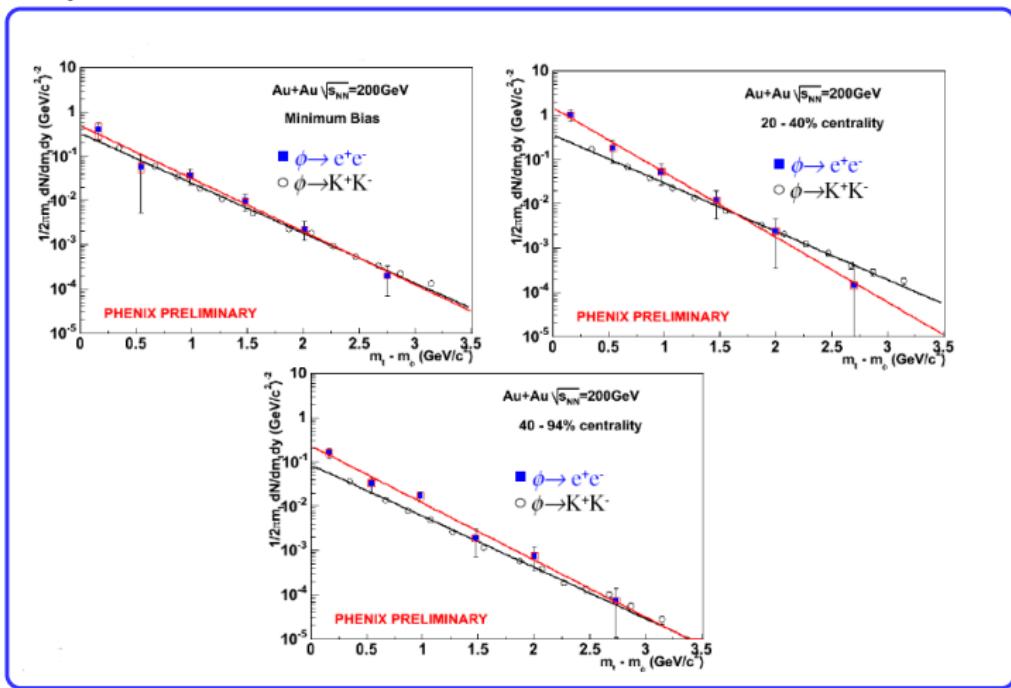
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Yield and Temperature measurement

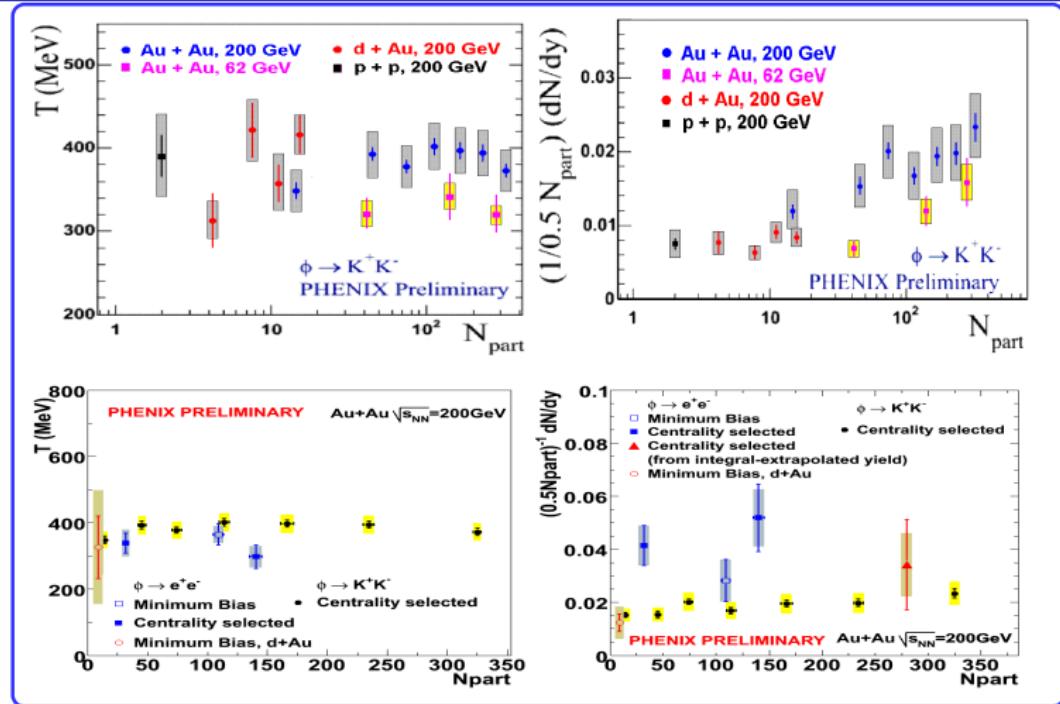
For yield and temperature calculation, the invariant $m_T - m_\phi$ spectra are fitted to function:

$$\frac{1}{2\pi m_T} \cdot \frac{d^2N}{dm_T dy} = \frac{dN/dy}{2\pi T(T + M_\phi)} \cdot \exp(-(m_T - M_\phi)/T)$$

For K^+K^- , this analysis was done for the case where both Kaons are identified.

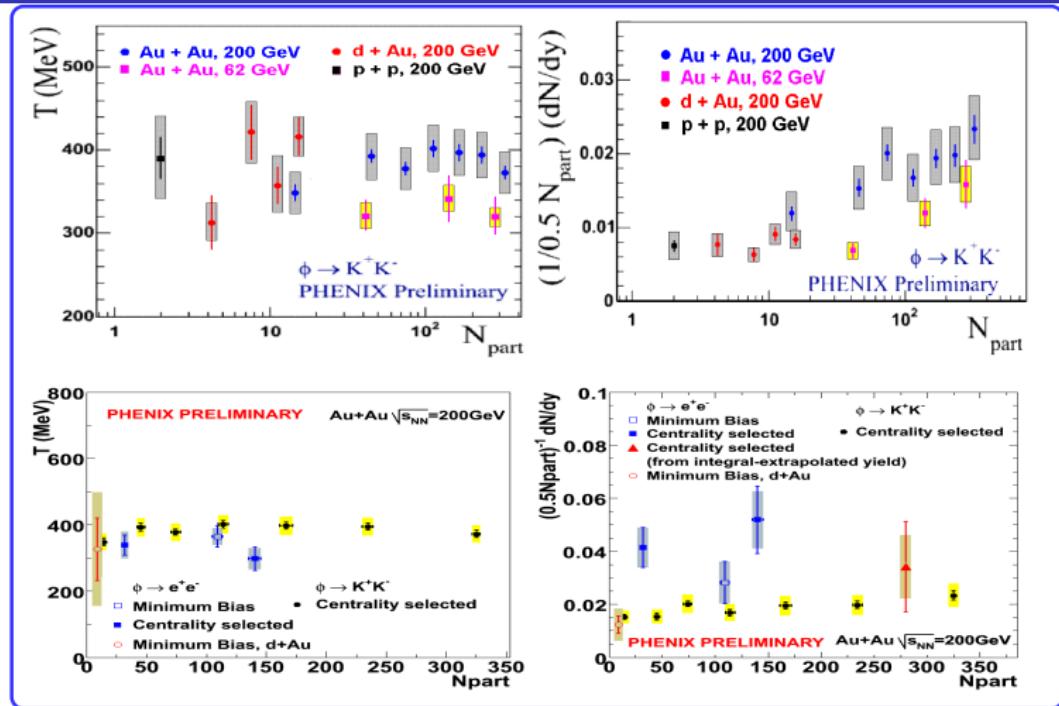


Summary of measured yield and temperature



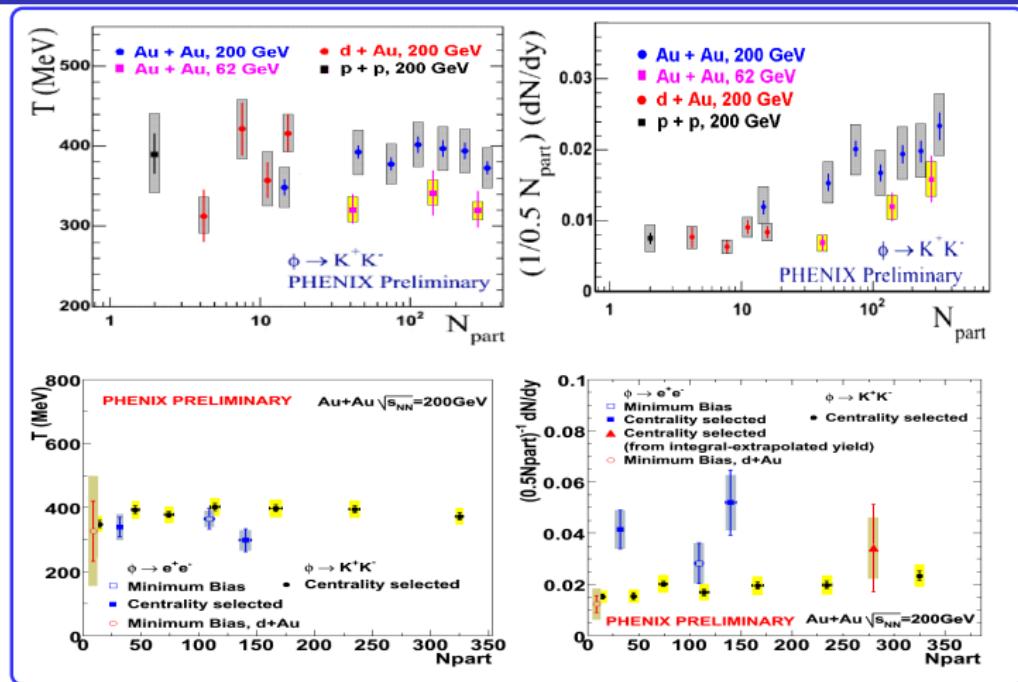
- temperature measured with leptonic channel is consistent to the Hadronic mode.
- temperature \sim same @ 62, 200 GeV, constant with N_{part}
- dN/dy grows with $\sqrt{s_{NN}}$ and Centrality.
- dN/dy in e^+e^- channel seems higher, compared to K^+K^- channel, but errors bars are large to make any conclusion.

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Summary of measured yield and temperature



- temperature measured with leptonic channel is consistent to the Hadronic mode.
- temperature ~ same @ 62, 200 GeV, constant with N_{part}
- dN/dy g Need HBD to improve the quality of dilepton measurements. will be installed in the upcoming run.
- dN/dy in statement

any conclusive

PHENIX

Hadron Blind Detector for PHENIX



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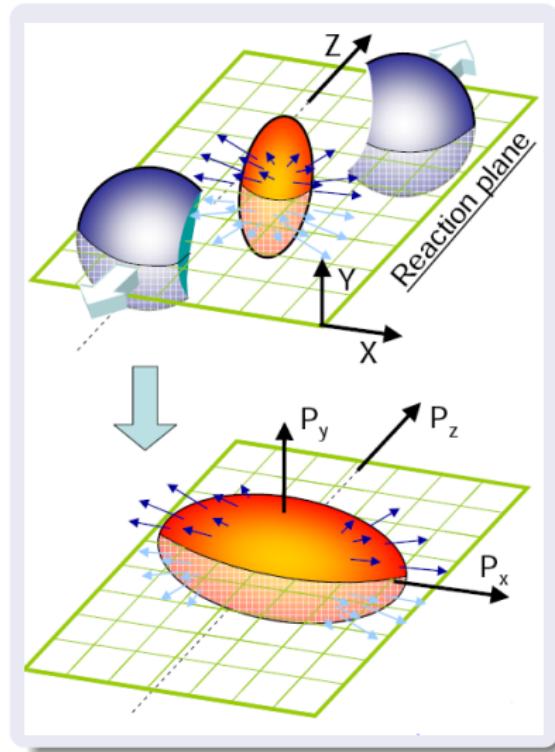
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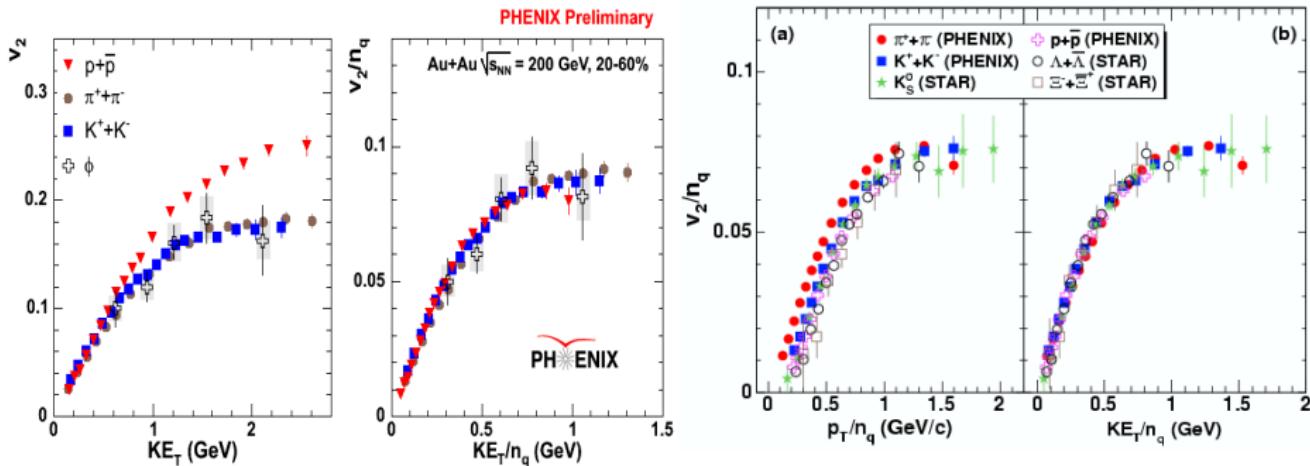
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6 Summary

Elliptic flow v_2

- v_2 provides early time information on the collectivity of particles from heavy-ion collisions.
- The initial geometrical anisotropy is transferred by the pressure gradients into a momentum space anisotropy.
- v_2 is defined by the 2nd coefficient of an azimuthal Fourier expansion of the transverse momentum spectrum around the beam axis.
$$E \cdot \frac{d^3N}{dp^3} = \frac{1}{2\pi} \cdot \frac{d^2N}{dp_T dy} \cdot [1 + 2\nu_1 \cos(2\phi) + 2\nu_2 \cos(2\phi) + \dots]$$
$$\nu_2 = \langle \cos(2\phi) \rangle$$





- At low p_T ($p_T \leq 2.0$ GeV/c), v_2 is consistent with the characteristic mass ordering expected from hydrodynamics.
- The p_T region (2 - 5 GeV/c) show a number of constituent quark (NCQ) scaling behaviour.
- ϕ also shows significant flow, with a similar trend as that π^\pm and K^\pm at higher p_T , consistent with universal scaling of v_2 per constituent quarks.

At RHIC the matter flows with partonic degree of freedom during the early stage.

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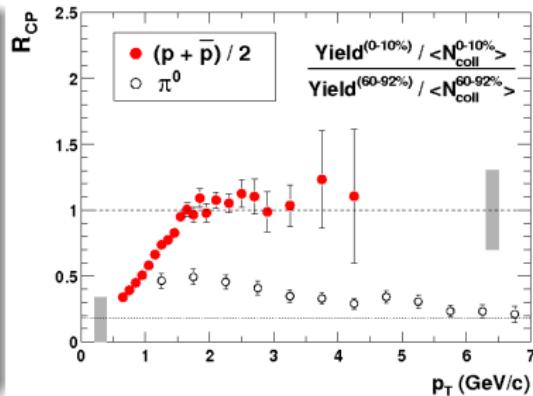
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The nuclear Modification factor R_{AA} is

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_Tdy}{\langle n_{coll} \rangle \cdot d^2N^{pp}/dp_Tdy}$$

R_{cp} is the ratio of central to peripheral yields scaled by their respective N_{coll} value.

$$R_{CP}(p_T) = \frac{N_{coll}^{peripheral}}{N_{coll}^{central}} \cdot \frac{d^2N_{AA}^C/dp_Tdy}{d^2N_{AA}^P/dp_Tdy}$$



Phys. Rev. Lett 91, 172301 (2003)

- Pions are suppressed in Central Au+Au collisions @ 200 GeV
- Protons show no suppression at 2-4 GeV/c.
- The suppression pattern depends on particle species.

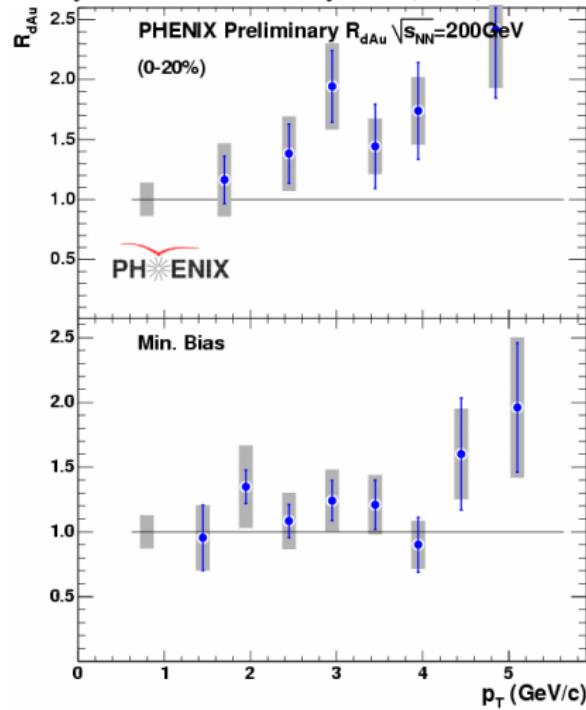
Systematic measurements of R_{AA} and R_{CP} for various particles helps to understand the nuclear medium effects on hadron production. ϕ plays an important role to disentangle mass or meson/baryon or quark content dependencies.

ϕ -Nuclear modification factor

in $d+Au$ 200 GeV

$$\phi \rightarrow K^+ K^-$$

J. Phys. G: Nucl. Part. Phys. 35 (2008) 044030

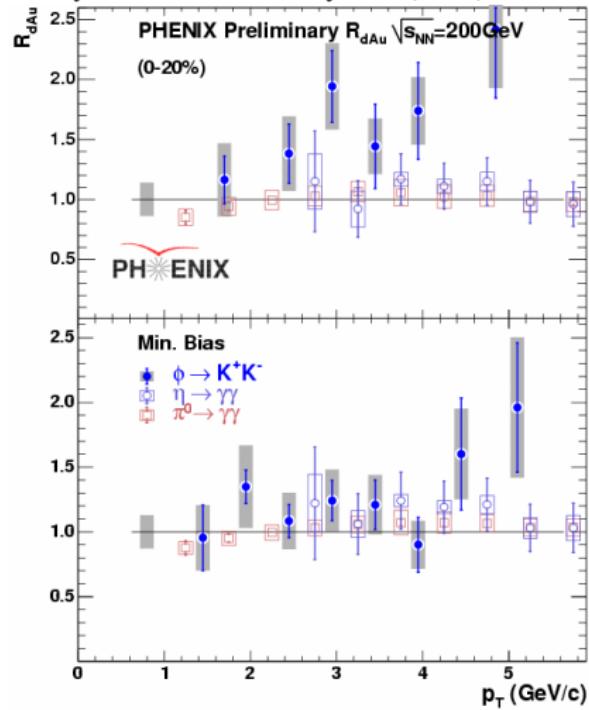


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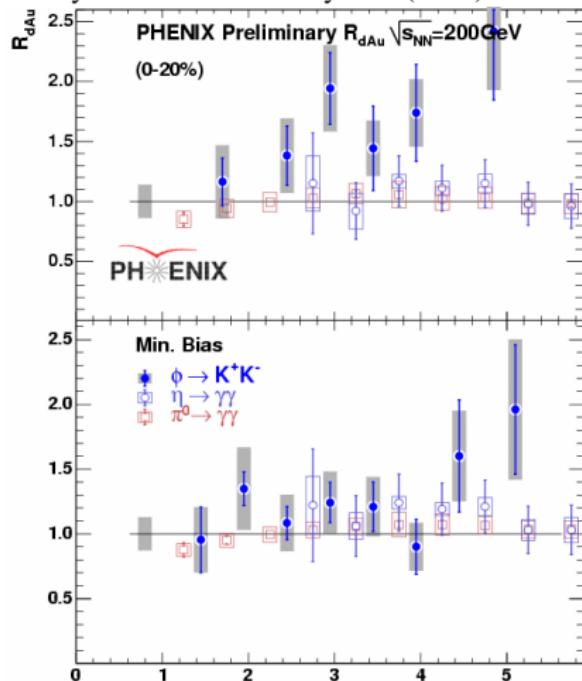


ϕ -Nuclear modification factor

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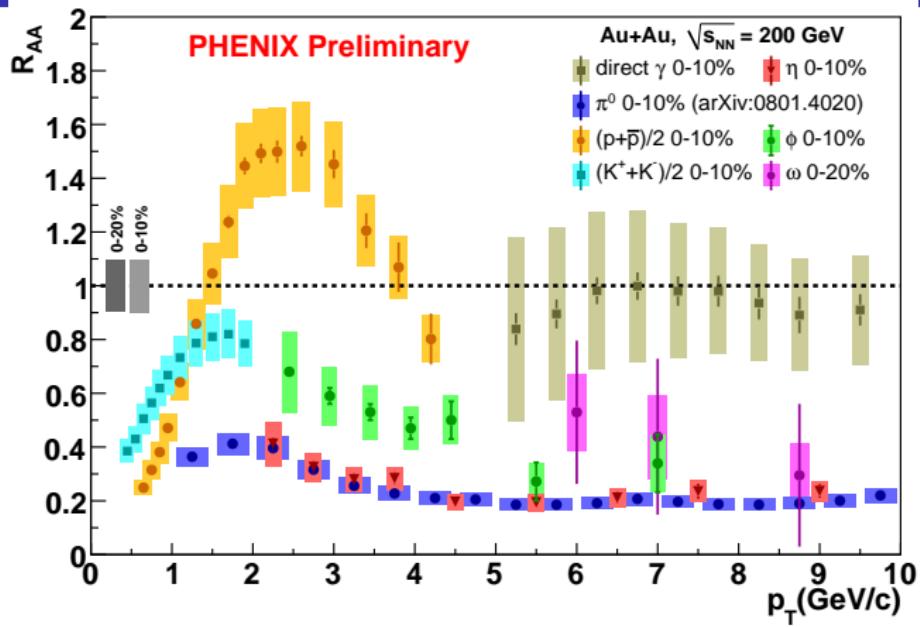
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- ϕ is not suppressed in d+Au
- R_{dA} of π^0 , η is consistent with 1. ϕ enhancement in 0-20%? (Cronin effect)

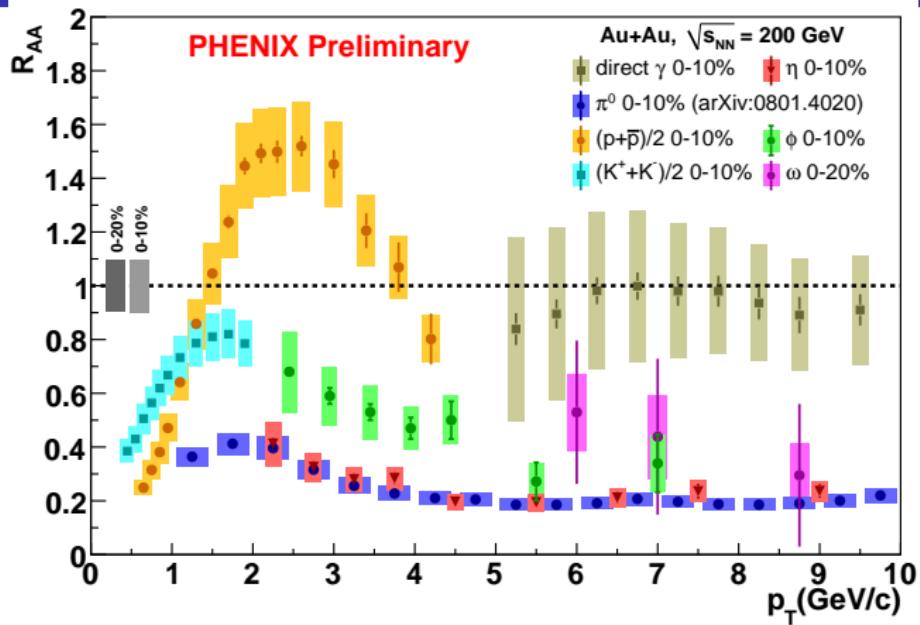
ϕ -Nuclear modification factor

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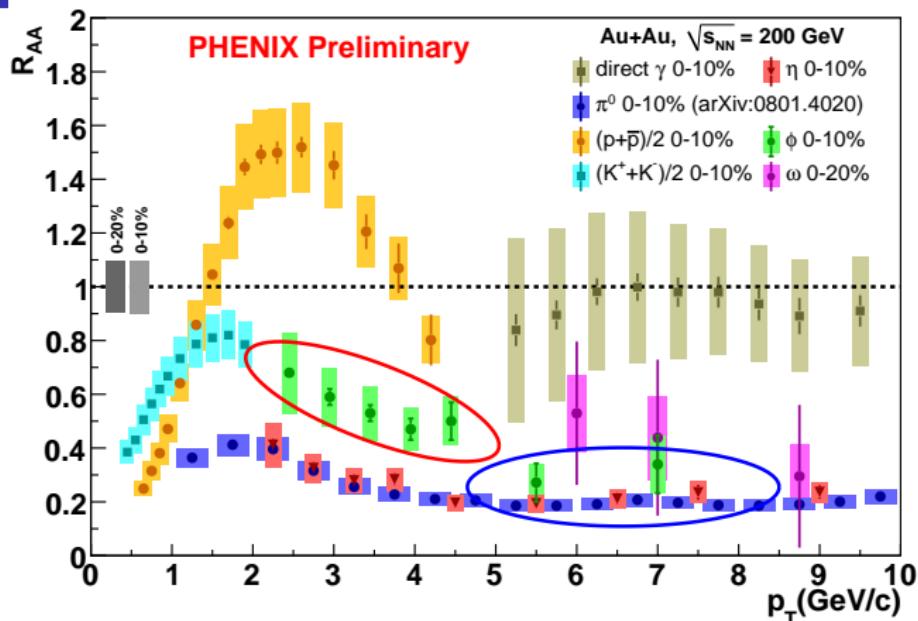


The known fact:

Hadron suppression patterns do not depend on the mass of the particles, but they are sensitive to the number of valence quarks.

ϕ -Nuclear modification factor

in Au+Au 200 GeV



ϕ meson does not fit into this picture...

At Intermediate p_T : It is more suppressed than protons but less than π^0 and η .

At high p_T : the ϕ -suppression level is similar to that of π^0 and η . Does suppression depend on quark flavor composition?

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PHENIX has measured ϕ -meson in $p + p$, $d + Au$ and $Au + Au$ collisions @ $\sqrt{s_{NN}} = 200\text{GeV}$ by K^+K^- and e^+e^- decay modes. Also $Au + Au$ @ 62.4 GeV, using K^+K^- .

The measurements using K^+K^- decay channels are complete in all systems. Different analysis techniques, yield same results in all the systems. Measurements cover wide p_T coverage(0-7GeV)

The leptonic channel measurements suffer due to combinatorial background and statistics in $Au + Au$ and $d + Au$. The results are expected to improve in future, with HBD that will be installed in upcoming run. The preliminary $p + p$ measurement exists.

The ϕv_2 is consistent with other mesons and follows Quark number + KE_T scaling.

In $d + Au$, no suppression is seen, but large error bars make room for Cronin enhancement.

The R_{AA} of ϕ -meson in $Au + Au$ shows similar suppression pattern to that of π^0 and η at high p_T , but at intermediate p_T , the suppression pattern is different.

A hint of quark flavour dependence !!!

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Comparison with star

